

Realism in the design process and credibility of a simulation-based virtual laboratory

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Abstract

The credibility of an instructional simulation is the most important issue in distance education, where it may replace hands-on activities. This credibility is based in large part upon verisimilitude, a perception strongly influenced by the simulation's realism. This paper presents a case study encompassing the design process of a simulation-based virtual laboratory, which was guided by a realism principle, and an investigation of its credibility among potential users. We found that many characteristics of the environment associated with the design principle favoured its credibility, but that others had widely varying, even opposite, effects among users. A user's prior experience was shown to play a crucial but intricate role in verisimilitude and credibility judgements.

Keywords

case study, credibility, experiment, post-secondary, simulation, virtual laboratory

Introduction

In their study of the credibility of a simulation-based learning environment, Hennessy & O'Shea (1993) pointed out that a knowledge of users' perceptions of credibility bears 'significant implications for simulation designers who want their systems to be of educational value and their interfaces to be designed in a principled way' (p. 130). They concluded that this whole issue, which had received little attention, was well worth further study. Since then, however, the few studies (Hatzipanagos 1995, 1997; Edward 1997) that have touched upon this subject have done so only in a partial or indirect way.

This paper contributes to this subject by reporting a case study encompassing the design process of a simulation-based environment and an investigation of its credibility among potential users. First, I will describe the environment itself, namely the virtual physics lab (VPLab) developed at Télé-université, a

distance education university. I will then show how a realism-based design principle, put forward at the onset of the project and applied throughout the design process of the environment, with the aim of maximising its credibility, shaped its characteristics and facilitated the work of the design team. Second, I will present a qualitative exploratory study of students' perceptions concerning the credibility of VPLab. I will focus on the role played by the various characteristics of the environment and by users' prior experience in the formation of these perceptions, and verify to what extent these match VPLab's designers' hypotheses.

VPLab

The expression 'virtual lab' is used to describe a large spectrum of products and systems, from simple simulations of phenomena (e.g., JAVA applets), to network-based systems allowing remote access to data or actual set-ups and full-fledged learning environments including simulated experiments, tools, and learning resources. VPLab,¹ which belongs to the

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¹The latest version of the VPLab prototype can be downloaded at <http://www.licefteluq.quebec.ca/gmec/vplab/lvp.htm>. Note that the VPLab interface is in English, but that the online help, the video library, and most multimedia documents are in French.

latter category, is a computer environment offering simulated experiments as well as multimedia explanations about the phenomena that the experiments investigate.

As designers of VPLab, our goal was to build an intuitive and enjoyable interactive environment with which learners could perform tasks similar to those carried out in real laboratories. We wanted to provide a context where they would feel that they are learning skills useful for real laboratory work, as opposed to just playing a videogame or something of the sort. We considered this credibility issue to be of utmost importance, at least for college and first-year university-level students enrolled in distance-education science programs, where environments like VPLab would most probably constitute one of the main opportunities, if not the only one, to perform lab-related tasks.

It is clear that not all aspects of laboratory work can be covered by the kind of simulations included in VPLab; sensory-motor aspects are notably absent. Yet many skills relevant to laboratory work do not rely upon such aspects. Planning of experimental steps, choice of measuring tools and measurement methods, assessment of uncertainty, gathering, and treatment of data are all examples of tasks involving high-level skills, which can be performed in a suitably designed simulation.

Let us now examine VPLab's main characteristics: its architecture, interface, tools, and resources.

Architecture and interface of VPLab

VPLab is a stand-alone application featuring multiple windows (symbolised by rectangles in Fig. 1) used for navigation, simulation, documentation, and note-taking in a lab notebook. When needed, VPLab also launches specific online documents (video clips, online help, lab instructions) in the user's default browser.

From a task-based perspective, VPLab is divided into five workspaces (the ellipses within the rectangles in Fig. 1): the Manipulation and Analysis workspaces, devoted to laboratory work, and the Presentation, Explanation and Theory/Applications workspaces, where one finds information (in multimedia format) about the real experiment, its simulation, and the physics and mathematics involved.

The simulation window (Figs 2 and 3) contains, in addition to navigation buttons common to all win-

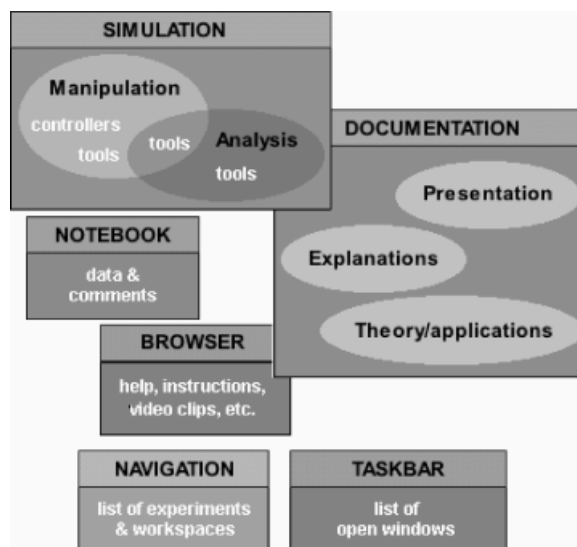


Fig. 1 Architecture of VPLab: windows (rectangles), workspaces (ellipses), and their content (white text).

dows, depictions of physical objects: experimental apparatus components, remote controllers, and measurement/analysis tools.

VPLab's tools

VPLab's simulated experiments (henceforth called 'simulations') appear as 2-D depictions of experimental set-ups (Fig. 2). As in an actual lab, the learner can act upon the set-up by moving its components; for some of these, this is done by simple click-and-drag, while for others one must click buttons on remote controllers. Each simulation contains a cue indicating the actual size of the set-up.

VPLab's navigation window can accommodate a dozen or so experiments. Three mechanics experiments are included in the actual prototype: one features a physical pendulum; the others, which take place inside a rotating merry-go-round, feature a simple pendulum and an air table, respectively.

A number of tools are available in VPLab. With the exception of the lab notebook, which has its own window, these are all located in the simulation window. One distinguishes *generic tools*, available in the Manipulation and (or) the Analysis workspace for all experiments, and *specific tools*, linked to the apparatus of a particular experiment and, thus, available only in the Manipulation space of that experiment.

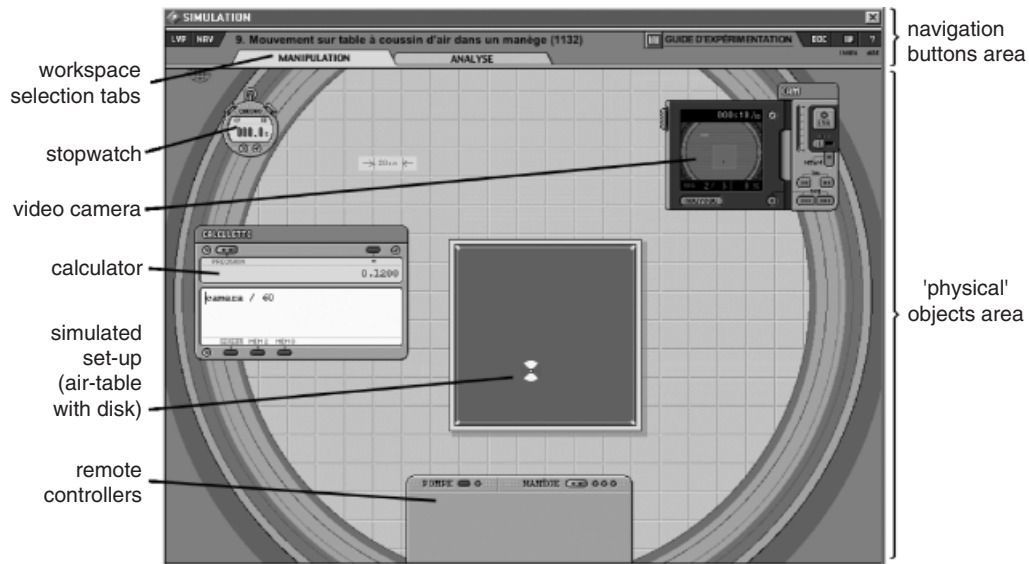


Fig. 2 Simulation window, displaying the Manipulation workspace of the experiment of the air table in a merry-go-round, and various tools (stopwatch, video camera, calculator, remote controllers).

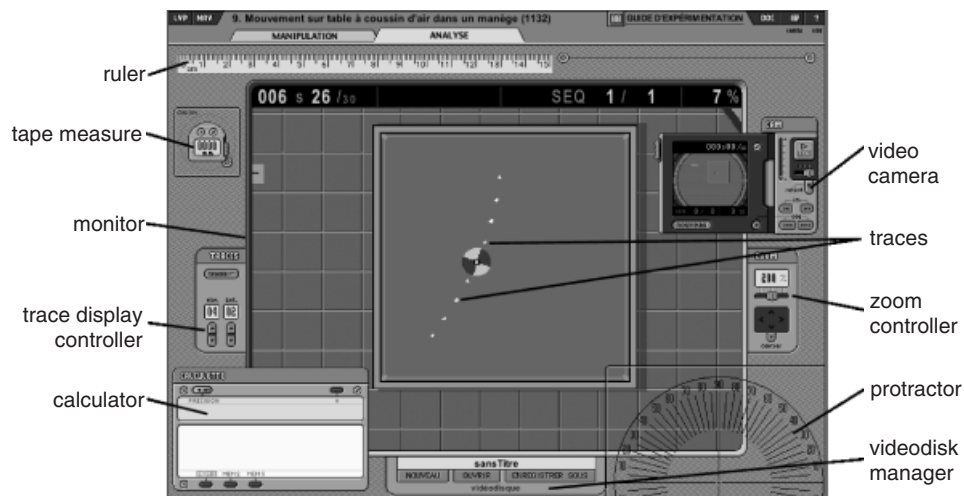


Fig. 3 Analysis workspace, with tools and (virtual) monitor displaying traces of the disk's motion.

There are eight generic tools in the actual prototype: a calculator, a stopwatch, a ruler, a protractor, a tape measure, a lab notebook, a camcorder, and a display monitor.

The calculator (Figs 2 and 6b) performs all standard math operations found in programming languages; values and formulae are entered through the keyboard. The stopwatch (Fig. 2), the ruler, and the protractor (Fig. 3) closely match up to their real-world counterparts. The digital tape measure (Fig. 3) is a

more exotic tool, looking quite different from actual similar instruments; it serves the same purpose as the ruler,² with the advantages brought upon by the digital readout.

The lab notebook (Fig. 4) is somewhat like a downsized spreadsheet. It holds pages that can be

²In the version of the prototype used for the study, the protractor and the ruler could only be rotated by 90° increments, so that one had to use the tape measure to make oblique length measurements.

	time	position	cm
1	1/15		
2		10,4	
3		11,4	
4		13,1	
5		15,0	

Fig. 4 Lab notebook.

saved as text files on the user's computer. These files can be reopened later in the notebook itself, or in any spreadsheet or word processor for treatment and/or graphical presentation. Data files can also be shared by students working on the same experiment, or sent to the teacher.

The last two generic tools are the camcorder and its associated display monitor (Fig. 3). In Manipulation space, the camcorder records the entire field of view at a rate of 15 fps on (virtual) videodisks. The camcorder is also used, in both Manipulation and Analysis spaces, to replay recorded sequences, either in the small viewport or, preferably, in the virtual monitor of the Analysis workspace. This monitor has 'digital zoom' capability, which, much like for digital cameras, does not increase resolution but still facilitates measurements. It also has a 'trace' feature, which superimposes temporal traces of objects over the currently displayed frame, in the manner of stroboscopic photography.

The lab notebook, the calculator, and all tools with digital readouts are part of a 'wireless network', which allow the notebook and the calculator to receive, upon a single click, any value displayed by these tools.

The specific tools are those associated with individual experiments, or small groups thereof. Some are remote controllers (Fig. 2), used either to move objects or apparatus parts in the simulation, or to switch components on and off. Others are data acquisition apparatuses, used for real-time measurement and 'wireless' transmission of relevant values to the notebook and calculator.

VPLab's resources

Two sets of resources are associated with VPLab. The first is composed of documents supplied by the authors of the environment and meant to be consulted by all VPLab users. These include video clips of real experiments, online help, and animated multimedia documents. The latter present, for each experiment or group thereof, explanations of differences between the real and simulated set-ups, demonstrations of meaningful physical situations, or mathematical and (or) physical explanations of the phenomena under study.

The second set consists of lab instructions (or any document judged useful for students), also specific to each experiment, prepared by individual instructors using the environment. These simple HTML documents, residing on a server, are accessed through the browser by clicking appropriate buttons in the simulation window. VPLab can be easily configured to retrieve the documents from any URL address.

Formal and functional realism in the design of VPLab

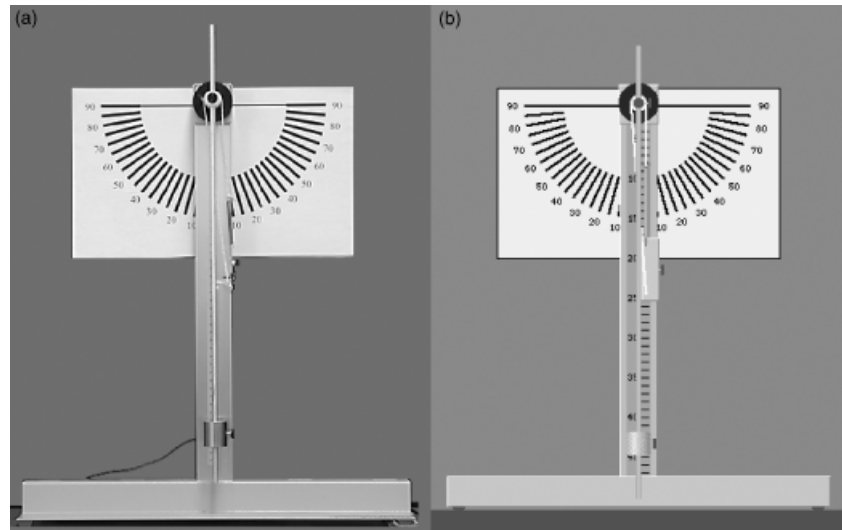
A principle named 'formal and functional realism' guided the design process of VPLab. The principle is closely related to the concepts of physical and functional fidelity proposed by Hays and Singer (1989). It also includes the criteria of possibility, plausibility, and existence, identified in studies on perception of television content (Elliott *et al.* 1983; Chandler 1997) as bases for judgements about verisimilitude, defined as 'the quality of appearing to be true or real' (Barker, 1988, p. 43).³

In practice, the principle translated into the following guidelines.

- The referents of simulations are experiments that are actually performed, in school labs or elsewhere.
- 'Physical' objects in the simulation window (set-ups, apparatuses, tools) look and work like objects that exist or could be made with actual technology, and that are found or could plausibly be found in a real laboratory.

³For a detailed discussion of the concepts of credibility, verisimilitude, realism, and fidelity, and of the criteria used in various types of judgements about these, see Francis (2003).

Fig. 5 Physical pendulum experiment: photograph of the set-up (a) and its depiction in the simulation (b).



- As much as feasible, users have no more, no less control over set-ups, apparatuses, and objects, nor can they obtain more information about the ongoing phenomena than would be displayed in a real laboratory.

- Measuring tools are given intrinsic uncertainty, and initial experimental conditions cannot be exactly replicated from trial to trial, similarly to what is observed with real tools and experiments.

As indicated by Hennessy and O'Shea (1993), such clear decisions made at the onset of the design process constituted a powerful guide. It gave the design team a common basis for discussions, as well as agreed-upon criteria for the numerous choices that had to be made. Let us illustrate this by a few examples.

- In a given simulation, the desirable level of interactivity, which would normally be an open, multi-dimensional discussion subject, was automatically determined by what actions are possible in the real experiment. In some instances, media- or budget-related constraints did not allow reaching this level, but in most cases the possibilities of action afforded by the simulation had to be limited. For instance, in the simulation used in the investigation, the merry-go-round can be made to rotate at only three predefined velocities whose values are not displayed, not because other configurations are not technologically possible, but because it was the way the real set-up worked.

- A 'physical' object in the simulation window could not be closed or minimised, but only dragged across the screen; it could not be resized or modified unless the same modification was possible with the

real object (for instance, the camera with its 'flappable' viewport).

- Functions of 'physical objects' could only be activated by 'physical' devices like push-buttons, swivels, sliders, or knobs; shortcuts and pull-down menus were not used.

As an added benefit, this principle helped maintain consistency within the environment, an important usability factor. At times, however, the principle conflicted with other usability and efficiency considerations. These situations were treated on an *ad hoc* basis, the principle being given priority unless the result turned out to be clearly unreasonable. Some examples are as follows:

- Balloon help, a powerful and very usable feature, as well as other forms of contextual help, were not implemented for physical objects, on the basis that in a real lab one has to look for instruction manuals normally stored in a designated place. Help thus consisted of online documents available through buttons in the navigation buttons part of the windows (Fig. 2). For consistency, all help files, not just those related to physical objects, were available in this way.

- Slight departures from fidelity were generally unavoidable. Figure 5 shows, for the physical pendulum experiment, the real apparatus (photograph on the left-hand side) and its depiction in the simulation (drawing on the right-hand side). The shape and proportions are closely reproduced, but finer details have been modified, notably the scale behind the pendulum's rod, which was enlarged and simplified to make it legible.

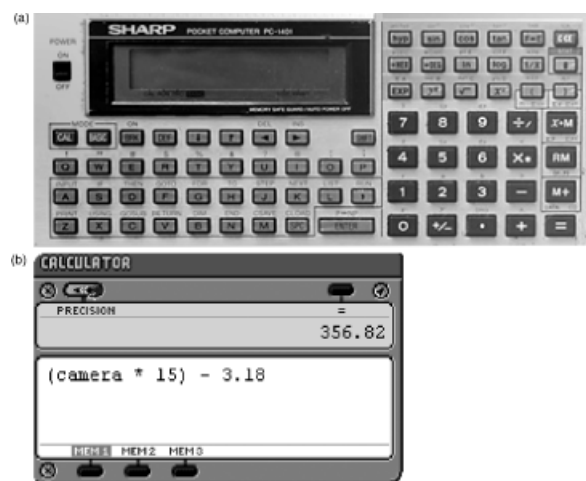


Fig. 6 Author's programmable calculator (a), from which VPLab's calculator (b) was loosely inspired.

- In a few cases, radical departures from realism had to be made. For instance, the calculator should have contained 77 buttons, including a keyboard and a keypad (Fig. 6a). This would have resulted either in a calculator hiding most of the screen, or else in buttons too small to bear legible inscriptions. Anyway, it did not seem reasonable, since a real keyboard is available, to put on the screen a simulated one, less efficient for data input (Mahach 1989). So the simulated calculator (Fig. 6b) ended up being quite different, both in appearance and in functioning, from its design referent, and even from any feasible calculator. The same applies to the tape measure, which had to be greatly modified to be usable in a 2-D environment. Although the idea of restricting the scope of simulated experiments to what is actually done in real labs is not new (see, for example, Lewis & Bullock 1972), very few designers of existing physics simulations purporting to be 'experiments' or 'virtual labs'⁴ seem to have followed this line of thought. These simulations generally allow the user to choose the initial values of variables with great precision, to modify physical constants (like friction), and to read real-time, exact values of most or all variables. Likewise, there is usually no random variation of parameters and variables. It is interesting to note that, by contrast, engineering

simulations often include such variations (Jayakumar *et al.* 1993; Gil *et al.* 2000; Hodge *et al.* 2000), except when the main goal of the simulation is to link experiments with theory (Darnel & Stern 1996; Ronen & Eliahu 2000).

But was this quest for realism a sound pedagogical choice? To answer this question, an important issue has to be addressed: it is the relationship between the complexity that generally ensues from increased realism, and learners' levels of expertise. Alessi (1988) has suggested that maximising realism (or fidelity) could be counterproductive for less experienced students. This has led to the design of simulations where the fidelity level changes according to the phase of instruction (Gil 2000).

Without calling into question Alessi's well-founded guidelines, I still think that the high realism of VPLab was fully justified. First and foremost, as explained before, credibility was an overriding concern. Any further lowering of realism – in addition to what was imposed by media limitations – could have put it at risk.

Second, one must note that VPLab belongs to two of the four types of simulations discussed by Alessi: physical and procedural. It is for physical simulations that Alessi suggests a low degree of realism for novice users. In VPLab, this is provided for by the Explanation and Theory/Applications workspaces, which contain highly simplified representations of the objects and phenomena found in the experiments. For procedural simulations, again for novice users, only presentation realism should be reduced, the problem being one of overburdening; as an example, Alessi mentions the 'bewildering array of instruments' in flight simulators. In this regard, one has to remember that realism in VPLab was not always maximised, due to software or media limitations, or even, as in the case of the 77-key calculator, out of sheer common sense.

Third, two empirical studies support our choice. In an investigation involving two simulation software packages, each sharing some important characteristics with VPLab, Hatzipanagos (1997) concluded that a combination of high presentation realism and low complexity of the physical situation (not unlike the one found in VPLab) was appropriate for novice learners. In a similar research comparing two versions of a simulated apparatus, one with a presentation realism level close to that of VPLab and the other schematic, Edward (1997) observed that the former rated higher

⁴See, for example, the 'experiments' at <http://www.physicslessons.com/iphysics.htm> and the 'virtual laboratory' at <http://www.phy.ntnu.edu.tw/java>

in terms of practical appreciation, motivation, and perceived learning among second-year engineering students who had no experience of the real apparatus.

VPLab may well have been designed in a way as to maximise its credibility, but how do the choices made by designers with this goal in mind actually translate when user perceptions are examined? This is what we tried to determine by conducting an exploratory investigation of credibility perceptions among potential users of VPLab.

Students' perceptions of VPLab's credibility

Method

Our sample consisted of 13 undergraduate students from universities in Québec, Canada, enrolled in chemistry, mechanical engineering, or physics programs, who volunteered to participate in the investigation. All but one were first-year students.

All subjects had previously conducted physics experiments in school laboratories at university level, and had attended lab-based physics courses. Some had performed real experiments similar to the simulation chosen for the investigation (the air table in a merry-go-round, shown in Fig. 2). However, none had had any prior contact with either VPLab or Télé-université. All subjects had much experience with computers and graphical user interfaces, but there was a broad spectrum of experience with simulation.

A three-step method was used to collect data. First, a written questionnaire was used to assess subjects' prior use of computers and simulation software, and to detect factors that could influence credibility judgements but were unrelated to VPLab's specific features.

Second, subjects were allowed to interact with VPLab through a series of tasks representative of those performed by novice users during an experiment. Before engaging in the tasks, subjects were told that the VPLab's general purpose was 'to teach experimental physics'. However, no mention was made of the realism principle or of designers' goals in this regard. While performing the tasks, subjects visited the Presentation, Manipulation, and Analysis workspaces, used most tools, and accessed various VPLab resources. Subjects were asked to 'think aloud', and to mention anything that seemed 'strange' or 'familiar'. Statements related to credibility and its main dimen-

sion, verisimilitude, were sometimes probed on the spot in order to clarify their meaning. Subjects and screen content were recorded on separate video tracks.

Third and last, subjects were debriefed in order to discuss any issues that could not be addressed while they were performing tasks. The debriefing included general questions, like what they felt about VPLab, as well as very precise queries targeting specific dimensions of verisimilitude judgements applied to well-defined characteristics of VPLab.

The total duration of sessions ranged from 2 to 3 h. Verbatim transcripts of the interviews, along with descriptions of video content, were loaded into a qualitative analysis software package for indexing purposes. The contents of the transcripts for each subject was thoroughly analysed, and then judgements from all subjects were regrouped under a few common themes.

Results

A number of credibility concerns involving characteristics of VPLab influenced by the design principle emerged from the investigation. I will present overall results for each of these characteristics; an in-depth, much finer analysis, including excerpts of interviews, can be found elsewhere (Francis 2003).

VPLab's main metaphor

VPLab's main metaphor – the virtual camcorder and monitor – was a source of negative verisimilitude judgements for several subjects. Some simply did not recognise what it represented, while others found such a device rather cumbersome and unlikely to be found in a real lab. Subjects were also bothered by characteristics such as the degraded quality of the zoomed-in pictures, the scale factor between the tools and the images, the trace function, and the impossibility of changing the camera viewpoint.

Video clips showing real experiments

The availability of video clips showing excerpts of the real experiment, which served as a referent for the simulation, contributed to favourable judgements for many subjects. These based their judgements on different aspects of the clips' content, like the role of the experimenter, the relative scale of the objects, and the behaviour of the disk.

Behaviour of simulation

Cues related to simulation behaviour – essentially the disk's motion – also contributed to favourable judgements. Again, different subjects relied upon different cues: for instance, the predictability of the disk's trajectory, the change in the disk's direction or in its rotation speed upon colliding with the table's sides, the change in the disk's motion when the speed of the merry-go-round was modified, the fact that the disk slowed down, and the rate of this deceleration. However, a given cue could sometimes lead to opposite conclusions depending on what was perceived or taken into account by different individuals. For instance, the disk's slow but perceivable deceleration, indicating that friction had been included in the simulation, favoured positive judgements, except for one student who had performed a similar (though not identical) experiment in which the disk decelerated faster.

Graphical attributes of the environment

The graphical attributes of the environment also contributed to contradictory judgements. The moderately realistic, videogame-like appearance of the simulations and tools was detrimental to credibility for some subjects, who saw it as a sign of a simplistic underlying physical model, perhaps aimed at younger, lower-level students. However, for at least one subject who held a strong opinion as to the realism of videogames he had played in the past, this very characteristic rather contributed to credibility. While agreeing that a more realistic depiction would increase verisimilitude, a number of subjects pointed out that VPLab was much more realistic than other instructional science software.

Measurements, measuring tools and methods, and their precision

Subjects who expressed judgements about the types of measurements performed in VPLab thought they were the same as in a real lab. However, judgements about the means of measurement (tools and methods) were much less unanimous. For the more usual tools, like the ruler, protractor, and stopwatch, negative judgements were expressed in relation to software-based limitations in manipulation. For more exotic tools like the digital tape measure and the calculator, negative judgements were associated either to the implausibility of finding them in an actual lab or to the

way they had to be handled, which was perceived as different from what was known or expected.

For several subjects, precision was an important criterion for verisimilitude judgements concerning measuring tools and methods. Many among them, notably engineering students, viewed precision of manipulations and tools as a crucial aspect of experimental work. At the same time, when asked to perform a task involving uncertainty assessment, many stressed the importance of uncertainty in real laboratory work. This tension between the quest for precision and the knowledge that precision will always be limited resulted in conflicting judgements. On the one hand, some subjects felt that the limited precision of the VPLab tools was detrimental to verisimilitude, referring to their experience in real labs or to the precision a computer simulation could offer. On the other hand, some reacted quite favourably to the necessity of assessing uncertainty like in a real experiment, sometimes pointing out that uncertainty assessment is one of the pedagogical objectives of school lab work.

Perceived freedom and control within the environment

For some subjects, the lack of heavy constraints on interaction with simulation objects and the freedom to choose among several possible experimental methods enhanced the verisimilitude of the environment. However, some of these subjects, along with others, found that the way they interacted with the disk, through mouse-driven actions, in order to launch it, gave them less precision than in a real lab. In accordance with the preceding observation, this was detrimental to verisimilitude.

Discussion

The results show that many characteristics of the environment resulting from the application of the realism principle contributed to its verisimilitude and (or) its credibility. The most important were the video clips of real experiments, the similarity between actions carried out in the simulated environment and those carried out during real experiments, the realism of simulation behaviour, and the uncertainty in measurements. However, other 'realistic' characteristics had negative effects; these characteristics mainly concerned VPLab's tools, such as the camera-monitor

system, the tape measure, and, to a lesser extent, the ruler and protractor.

The investigation also revealed the complex nature of the process leading to verisimilitude or credibility judgements. On the one hand, different subjects could base their judgements on completely different characteristics of the same object or behaviour. On the other hand, a given characteristic could sometimes lead to different, even contradictory judgements.

These widely varying results can be attributed to the intricate way in which subjects' attitudes, dispositions, and prior experience influence verisimilitude judgements. In expressing their judgements, subjects surely considered realism, but they also drew heavily from their prior experience of laboratory work, sometimes with related set-ups that just happened to be quite different from VPLab's, and of other kinds of software and simulations.

For instance, the verisimilitude of the camera-monitor system was judged relatively low overall, probably because subjects had never used or seen such an apparatus in a school lab. Such systems, though used in schools throughout the US, are virtually unknown in Québec. By contrast, the trace function of the system, whose verisimilitude was judged quite low by many subjects (and could be barely justified even by the designers themselves), was nevertheless the object of positive verisimilitude judgements among some of the subjects, who had previously used real tracing systems, albeit completely different ones, which did not rely upon a video camera.

Similar reasoning applies to the case of the ruler and the protractor, which, though quite realistic, received negative verisimilitude judgements from subjects who compared their precision to that of their real counterparts, or compared using these tools to employing more precise and convenient measurement devices available in CAD software. Likewise, the videogame appearance of the objects in the simulation was detrimental to VPLab's credibility as a whole for many subjects, as the designers had expected, but favoured it for others, who compared it with other educational software, or even with videogames.

Conclusion

The virtual physics lab is a simulation-based environment aimed at teaching experimental physics. It

was designed according to a realism principle with the goal of enhancing its credibility. This principle also proved to be a valuable tool in the design process itself, acting as a framework for discussions and decision-making.

The credibility of a prototype of VPLab was then assessed in an exploratory study among potential users. This investigation revealed, within the limits inherent to this kind of small-scale, qualitative study, that many of the characteristics of VPLab that resulted from the application of the principle did indeed elicit favourable verisimilitude judgements and contributed to its credibility, while others had opposite or even contradictory effects across subjects. This is explained by the fact that users' dispositions and prior experience relative to laboratory work and software use play an intricate but crucial role in the development of these judgements.

In addition to realism – and, in this regard, photo-realistic depictions would be useful – students' prior experience should therefore be given much attention if one wants to offer credible learning situations in simulation-based virtual laboratories. When feasible, it should be done at the design stage, but this issue could also be addressed by providing learners, in the same way as it was done in VPLab for the main experimental set-ups, with referents for all simulated objects in the environment and their intended ways of use. Finally, pedagogical objectives, which may also influence verisimilitude, should be clearly stated before students start working in the environment, which is sound practice anyway.

To increase and refine our knowledge of this subject, it would be interesting to extend the study to other virtual laboratories or similar environments, and to conduct quantitative studies involving large numbers of students using these environments in real learning set-ups. It would also be worth investigating, either in qualitative or quantitative studies, the role played by interaction between students, or between student and instructor, in the evaluation of credibility.

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